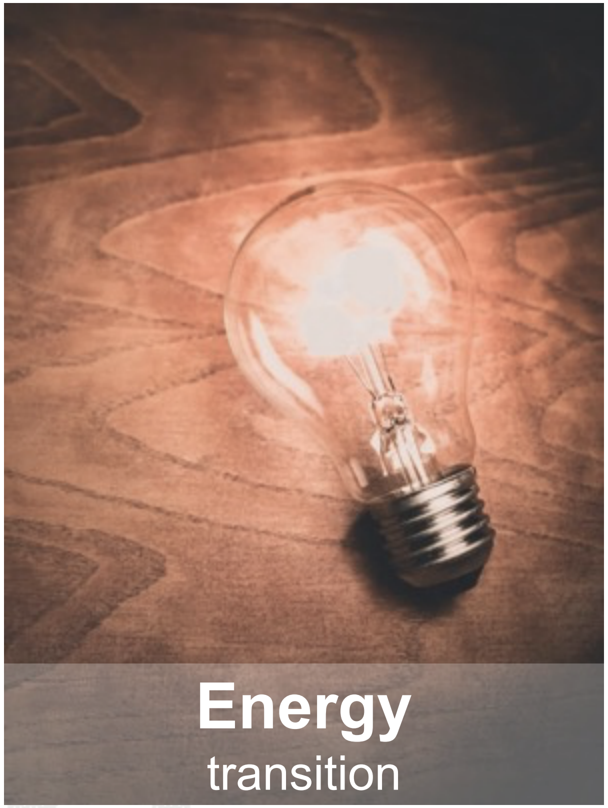
MaREI
Energy • Climate • Marine

Incorporating renewable gaseous fuel in future energy systems

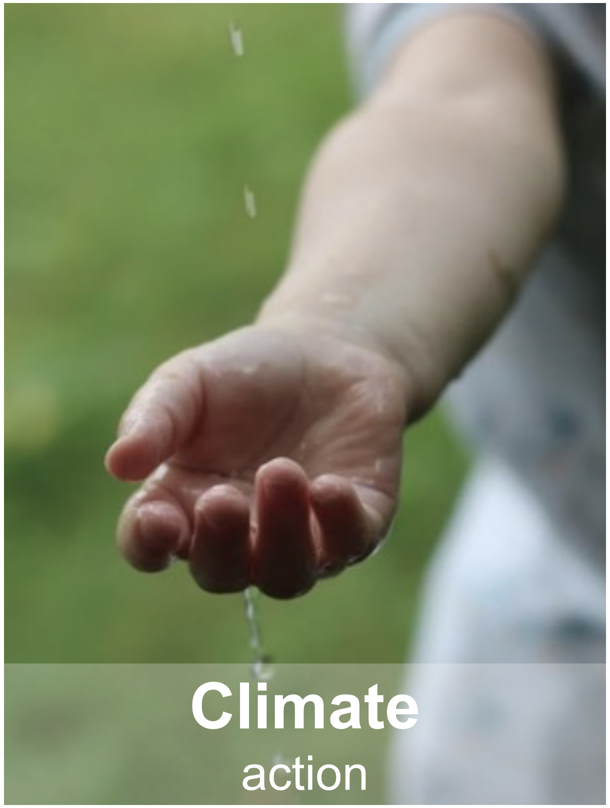
Professor Jerry D Murphy, Director of MaREI centre
Chair of Civil, Structural & Environmental Engineering
Leader International Energy Agency Bioenergy Biogas Task

8th International Renewable Energy Conference Thursday
October 10th, 2019

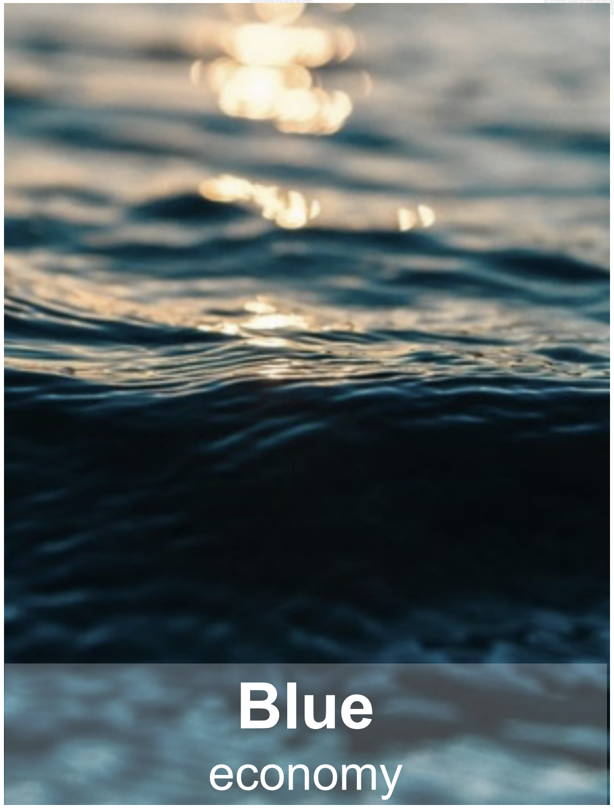
OUR
MOTIVATIONS



Energy
transition



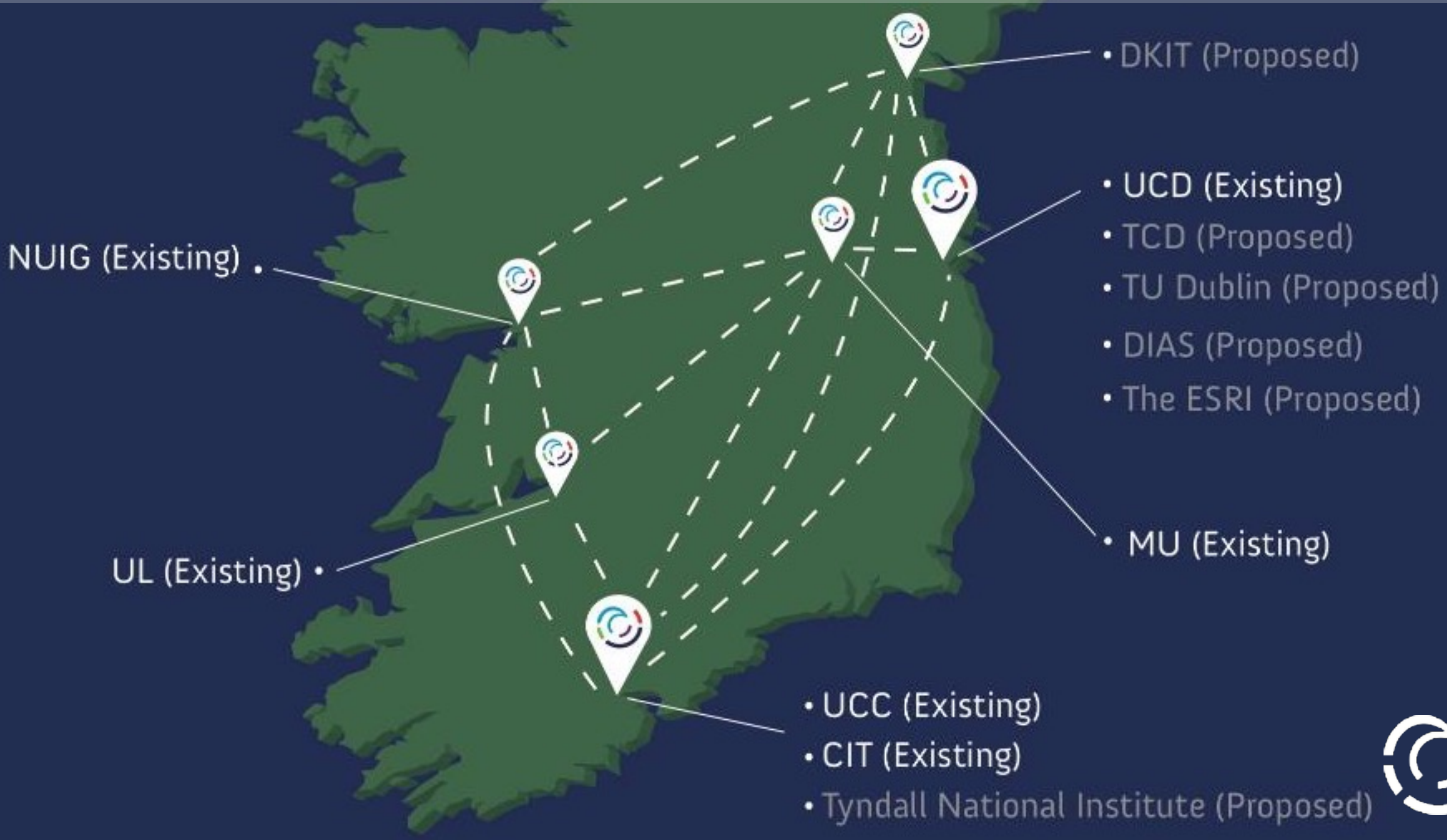
Climate
action



Blue
economy

OUR

Partner Institutions



- DKIT (Proposed)
- NUIG (Existing)
- UCD (Existing)
- TCD (Proposed)
- TU Dublin (Proposed)
- DIAS (Proposed)
- The ESRI (Proposed)
- UL (Existing)
- MU (Existing)
- UCC (Existing)
- CIT (Existing)
- Tyndall National Institute (Proposed)

Progress
TO DATE

200

multi-disciplinary researchers across our institutional partners

50

industry partners including Start-Ups, SMEs, and Large Enterprises

12

institutional partners combining Ireland’s best talent in energy and marine research

36

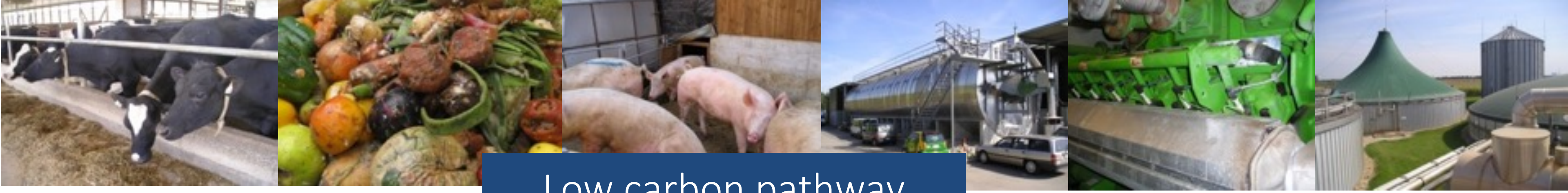
collaborating countries across industry, academia, and government

40%

of departees moving to industry as a first destination

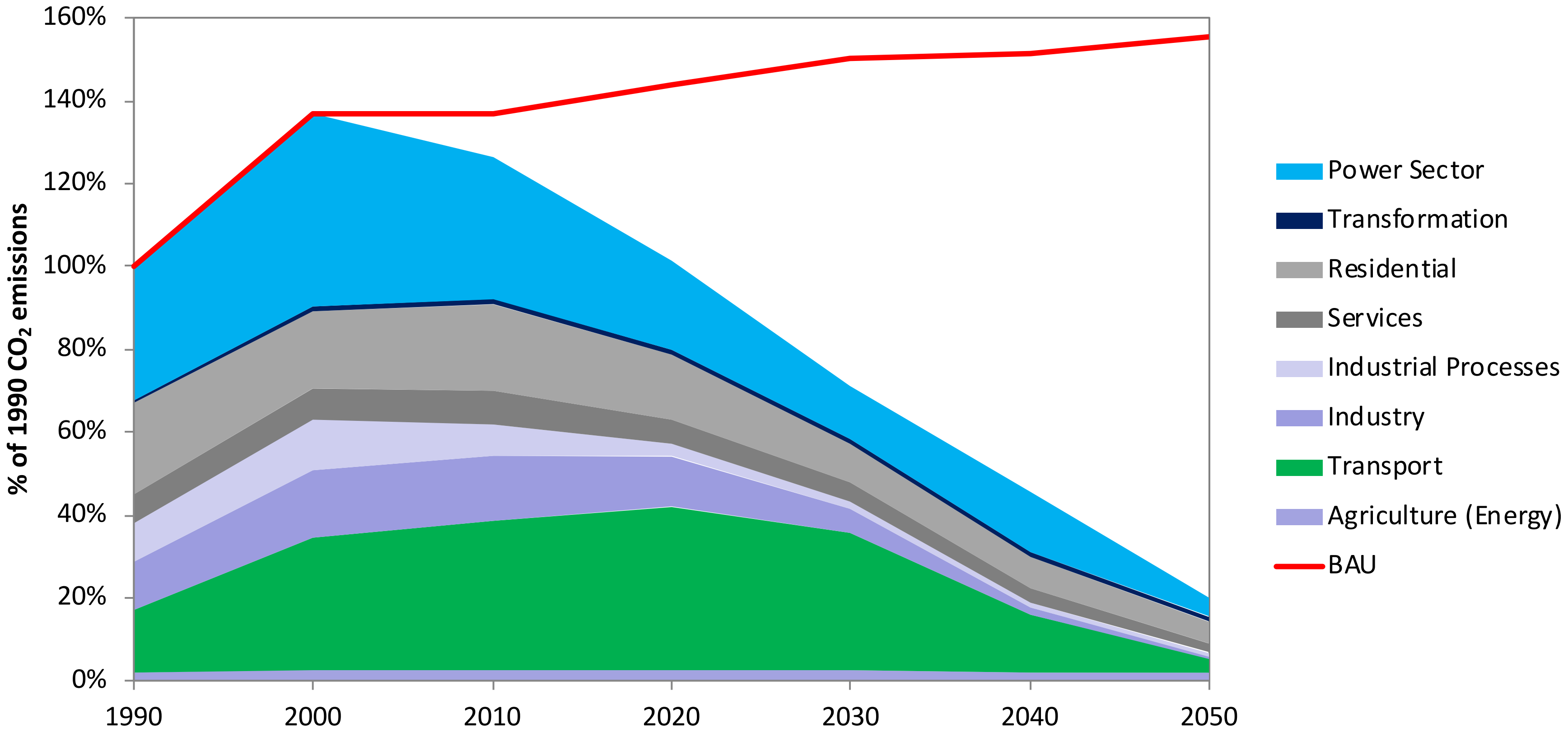
€63m

funding secured from industry, exchequer, and non-exchequer sources



Low carbon pathway

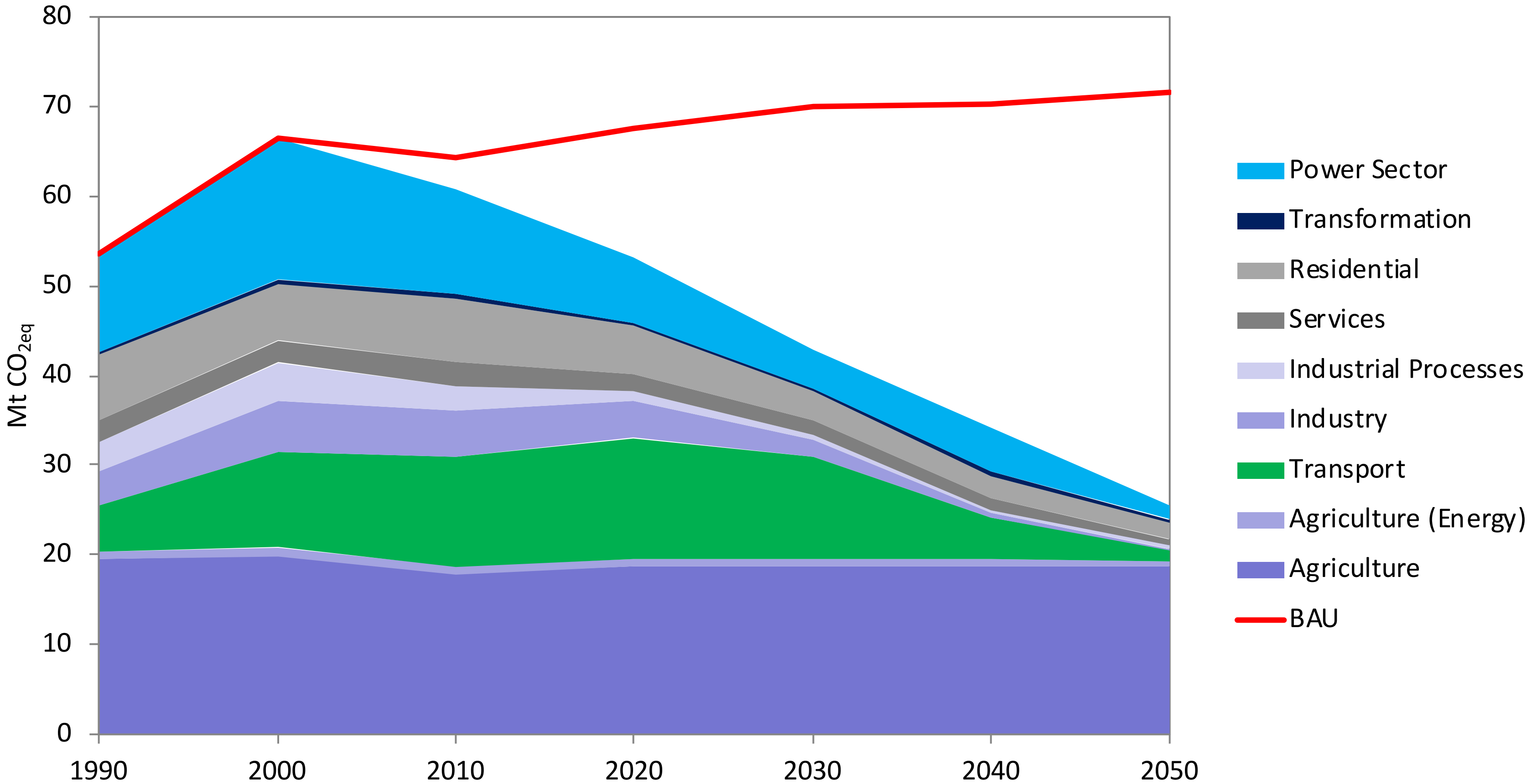
Ireland’s Low Carbon Pathway to 2050



Source: MaREI Energy Policy and Modelling Group

It is not all about electricity

But 80% CO2 reduction = 50% GHG reduction



Source: MaREI Energy Policy and Modelling Group

Limiting temperature rise to 2D is challenging

Limiting Emissions to 2DS

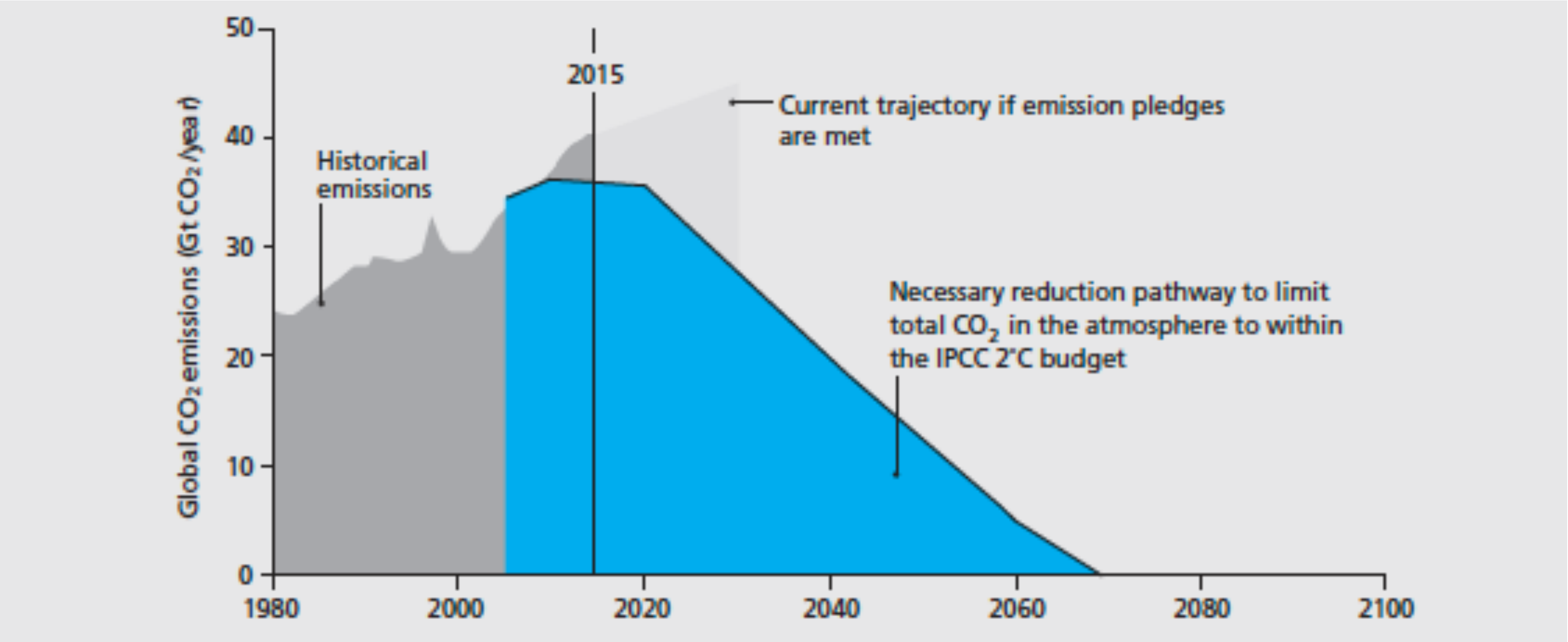


Figure 1 Emission pathways required to limit emissions to within the IPCC budget for 2 °C. N.B.: the carbon budget of approximately 800 GtC is the total area under the emissions (in pink). Source: adapted from Anderson and Peters (2016).

Source: EASAC (2018) Negative Emission Technologies: What role in meeting Paris Agreement targets?

We need carbon capture & sequestration

Limiting Emissions to B2DS-Bioenergy with Carbon Capture

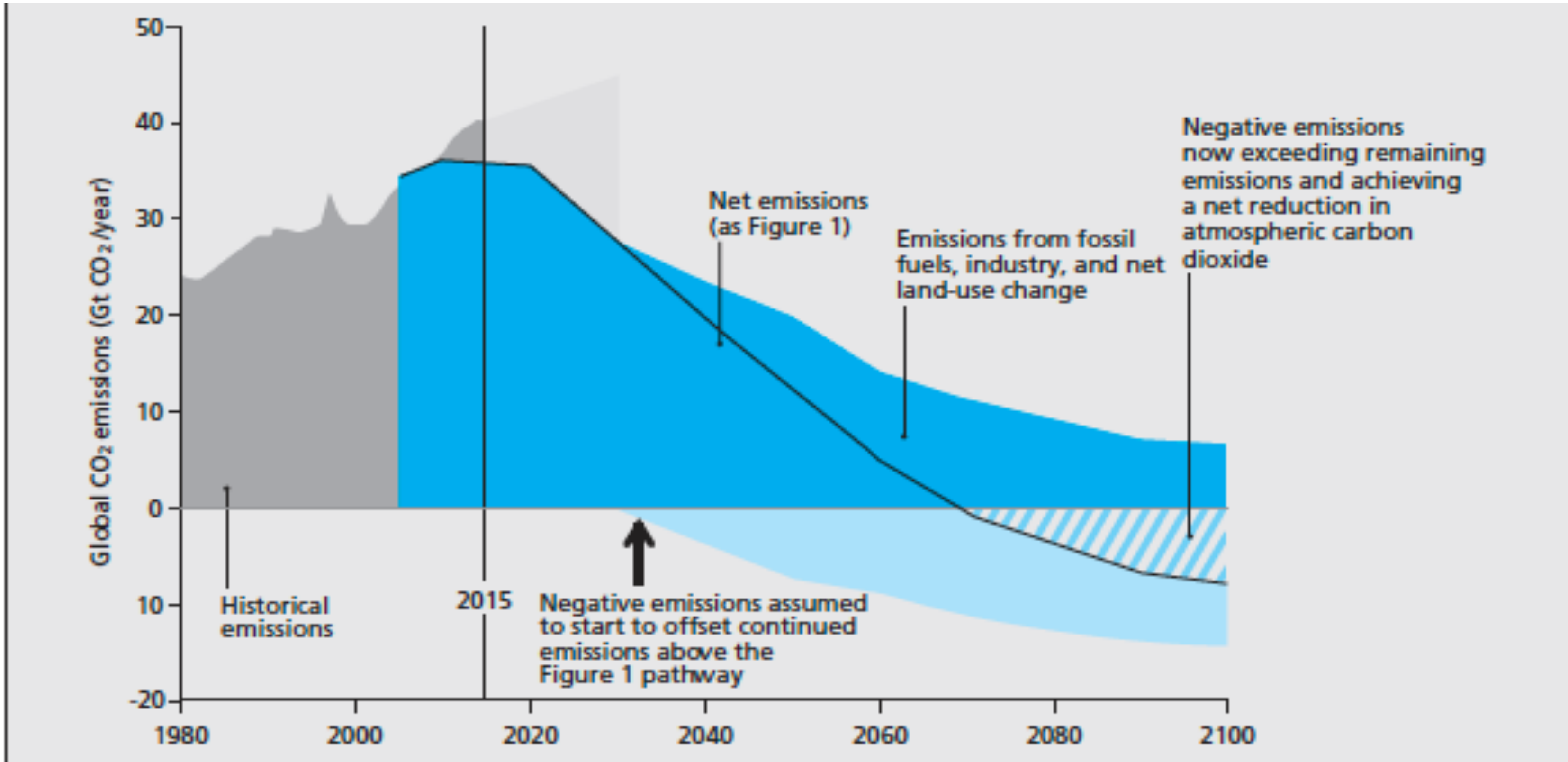
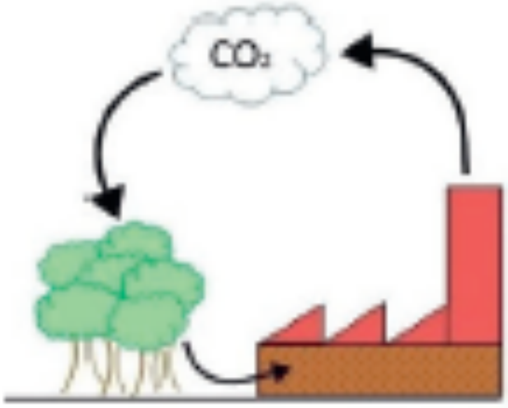


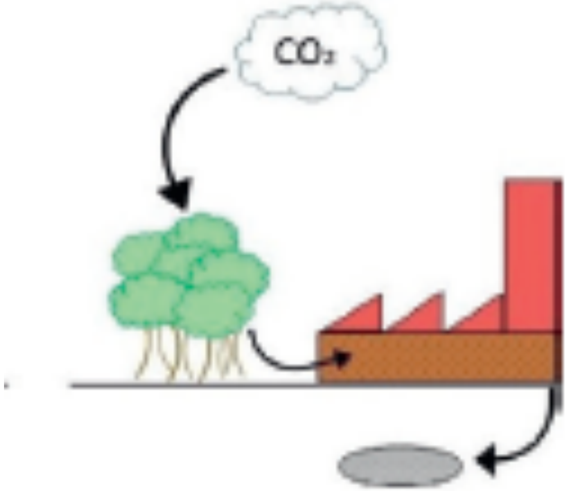
Figure 2 Inclusion of CO_2 removal in scenarios, thus allowing larger emissions without breaching the IPCC carbon budget. Source: adapted from Anderson and Peters (2016).

Source: EASAC (2018) Negative Emission Technologies: What role in meeting Paris Agreement targets?

Bioenergy with carbon capture & sequestration



CO2 neutral



CO2 negative

Source: EASAC (2018) Negative Emission Technologies: What role in meeting Paris Agreement targets?

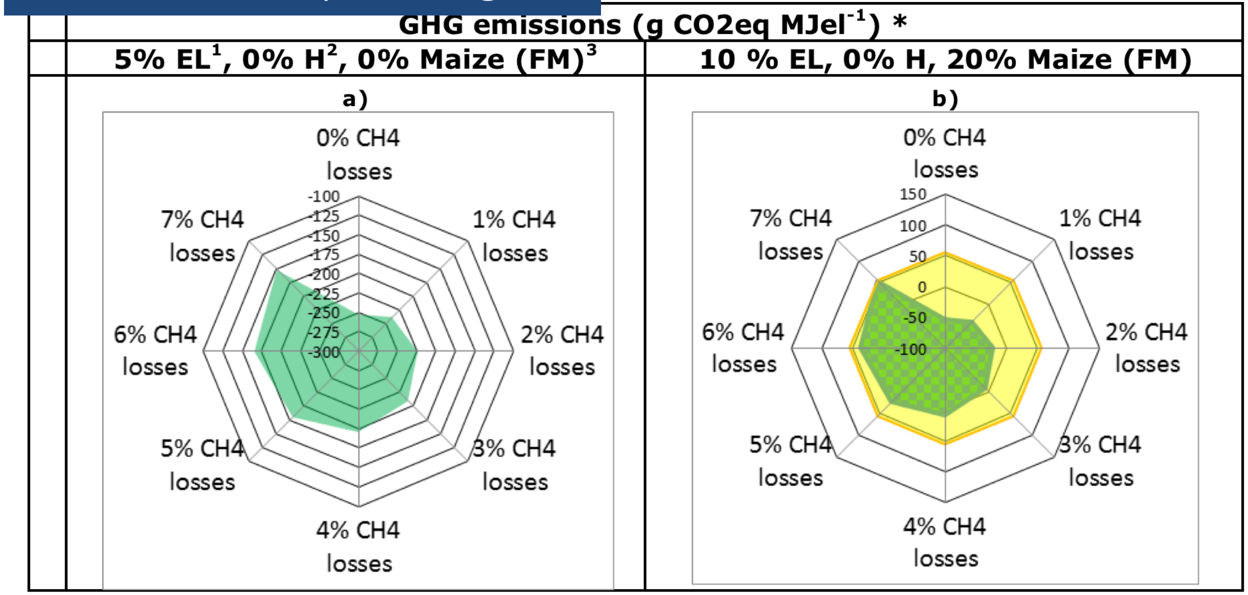
Sustainability of biogas

METHANE EMISSIONS FROM BIOGAS PLANTS

Methods for measurement, results and effect on greenhouse gas balance of electricity produced

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: 2017: 12



All slurry

20% Maize 80% slurry

Open slurry storage emits 17.5% of methane
At 2% methane slippage:

- Biomethane from slurry GHG negative feedstock (-250 g CO2/MJ)
- Biomethane from 20% Maize and 80% Slurry GHG still negative

California Air Resources Board (CARB) awarded a Carbon Intensity (CI) score of -255 gCO2e/MJ for a dairy waste to vehicle fuel pathway.

Carbon Efficient Farming / Carbon Neutral Breweries / Advanced Biofuel from parklands

BIOGAS IN SOCIETY
A Case Story

ORGANIC BIOGAS IMPROVES NUTRIENT SUPPLY

KROGHSMINDE BIOENERGY I/S, DENMARK

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: February 2019

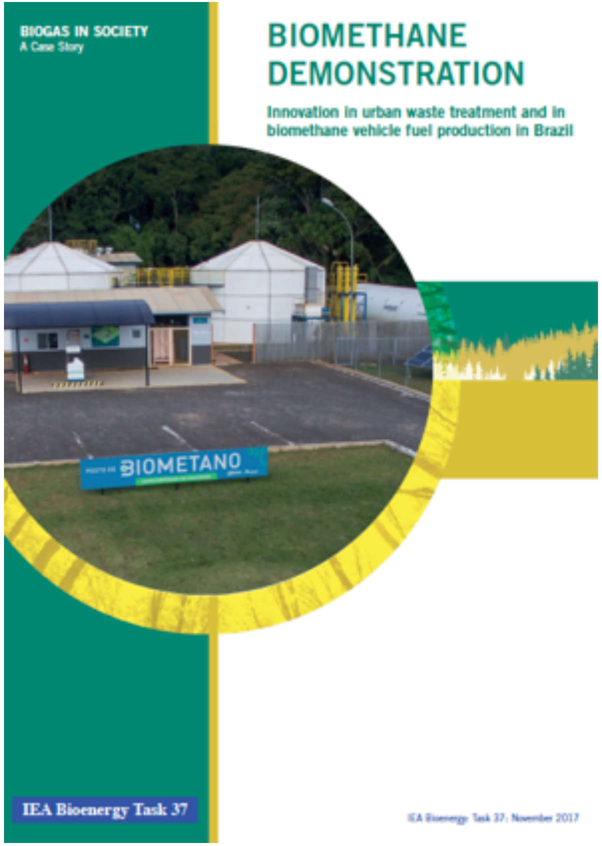
BIOGAS IN SOCIETY
A Case Story

GÖSSER BREWERY

THE ROLE OF BIOGAS IN GREENING THE BREWING INDUSTRY

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: December 2018



BIOGAS IN SOCIETY
A Case Story

BIOMETHANE DEMONSTRATION

Innovation in urban waste treatment and in biomethane vehicle fuel production in Brazil

IEA Bioenergy Task 37

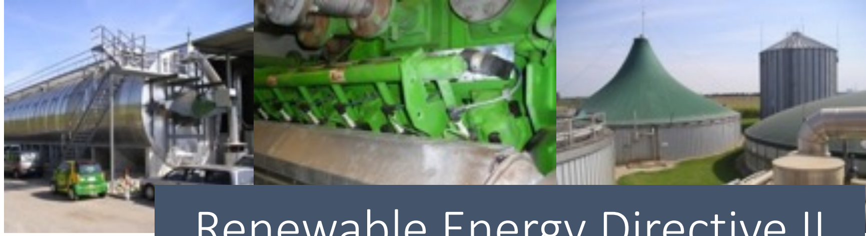
IEA Bioenergy: Task 37: November 2017

Milk from 140 cattle farm assessed as GHG negative at -0.82 kg CO2/ l produced.

Carbon Neutral Brewery
In Austria

65 cars fueled by grass cuttings from 400 ha of campus parkland in Brazil

Renewable Energy Directive II



Renewable and Sustainable Energy Reviews 115 (2019) 109347

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Can green gas certificates allow for the accurate quantification of the energy supply and sustainability of biomethane from a range of sources for renewable heat and or transport?

Aoife Long[a,b], Jerry D. Murphy[a,b,*]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland

1. GHG savings required by the recast RED are lower for transport than heat (65% vs 80%);

2. The FFC is higher for transport than heat (94gCO2/MJ vs 80 g CO2/MJ) making it easier to satisfy transport.

3. The efficiency of heat conversion must be included; this is not the case for transport.

4. For transport the recast RED methodology employs a field to tank analysis as opposed to a field to wheel. If the analysis were feedle to wheel typically biomethane underperforms as compared to diesel by about 75%.

5. This effect is further exacerbated by the fact that the recast RED counts advanced transport biofuel as twice the energy in the fuel.

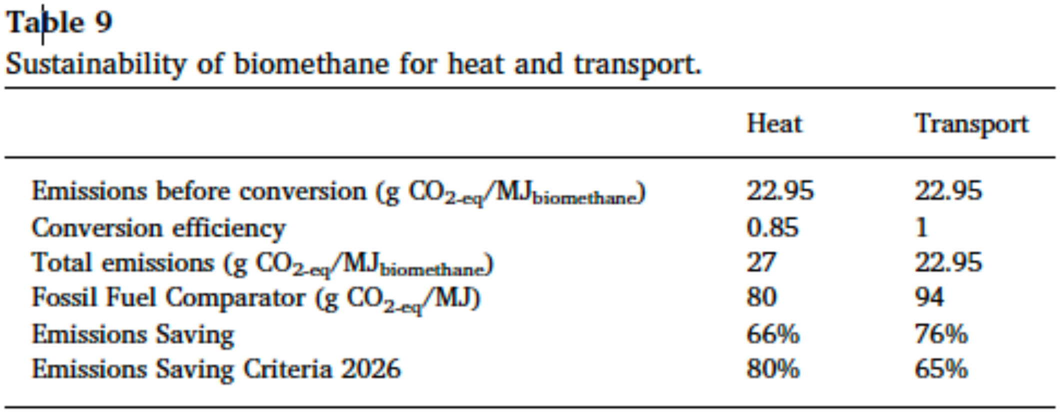
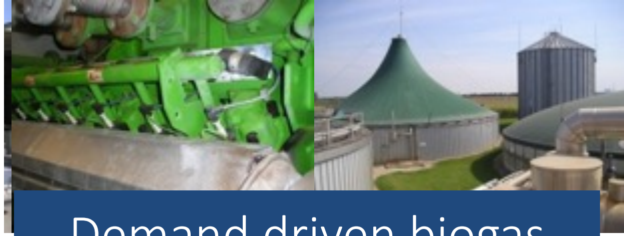
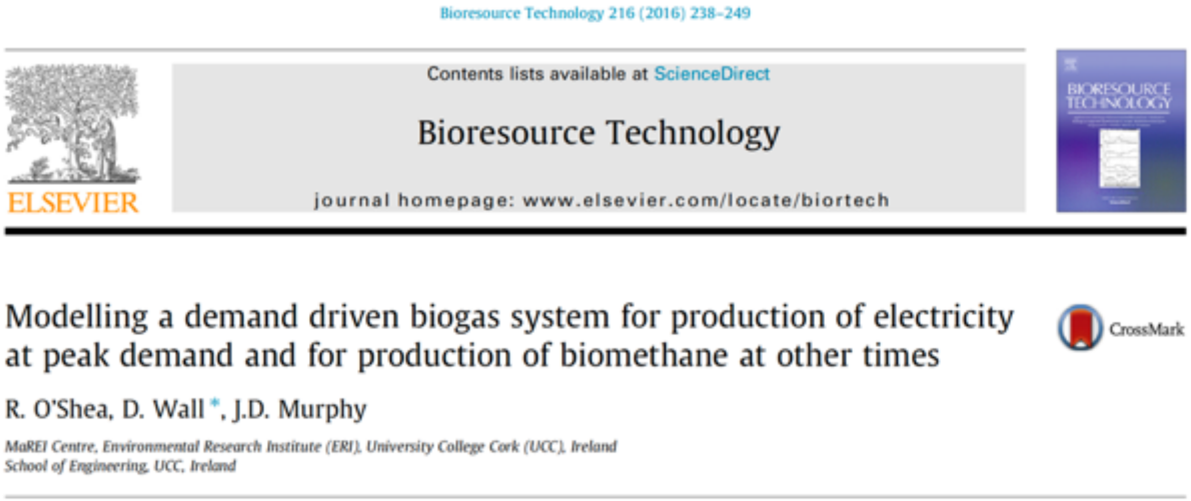


Table 9
Sustainability of biomethane for heat and transport.

	Heat	Transport
Emissions before conversion (g $CO_{2\text{-eq}}$/$MJ_{biomethane}$)	22.95	22.95
Conversion efficiency	0.85	1
Total emissions (g $CO_{2\text{-eq}}$/$MJ_{biomethane}$)	27	22.95
Fossil Fuel Comparator (g $CO_{2\text{-eq}}$/MJ)	80	94
Emissions Saving	66%	76%
Emissions Saving Criteria 2026	80%	65%



Demand driven biogas



Bioresource Technology 216 (2016) 238–249

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Modelling a demand driven biogas system for production of electricity at peak demand and for production of biomethane at other times

R. O'Shea, D. Wall [*], J.D. Murphy

MaREI Centre, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
School of Engineering, UCC, Ireland

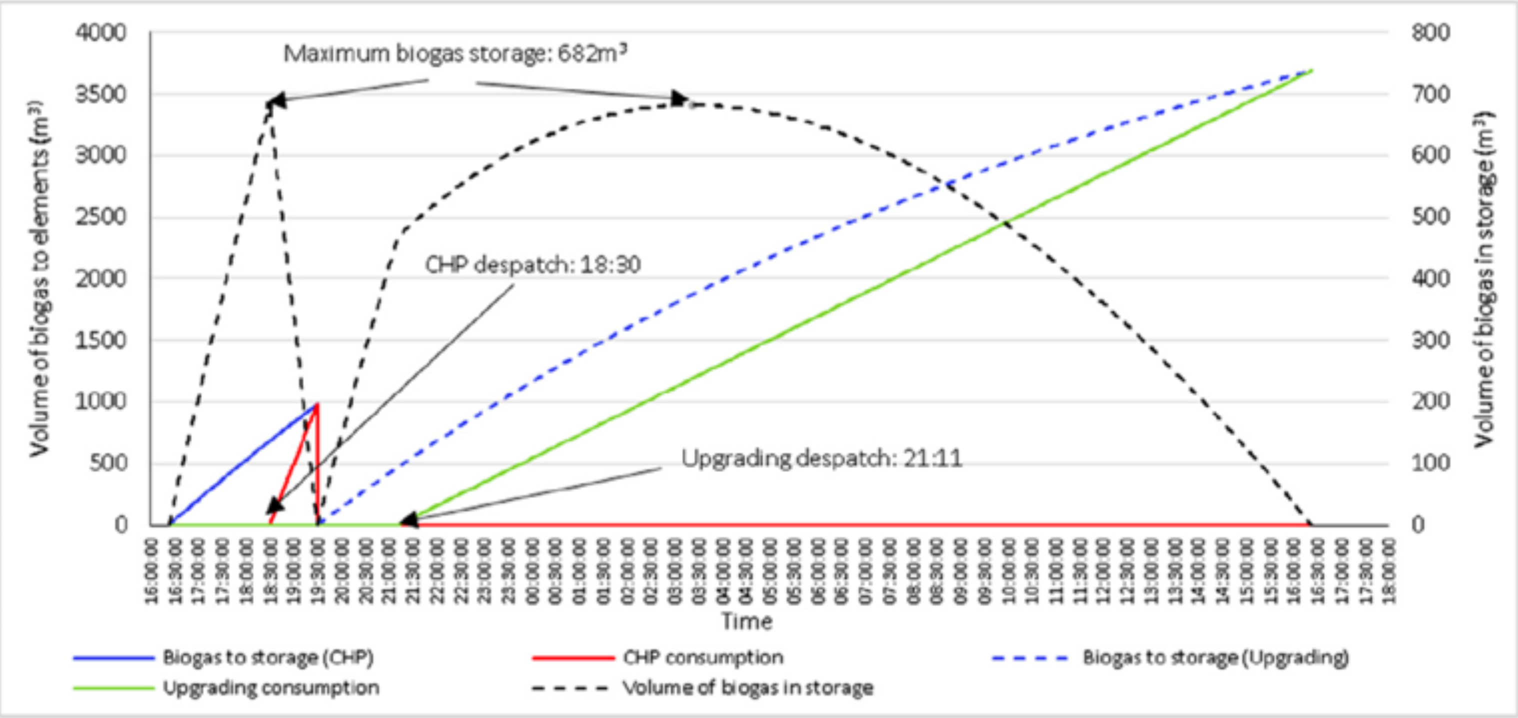


Fig. 4. Example of biogas flows in pulse fed reactor. Feedstock is grass silage, organic loading rate of 2 kg VS/m^3/day, reactor volume of 4000m^3.

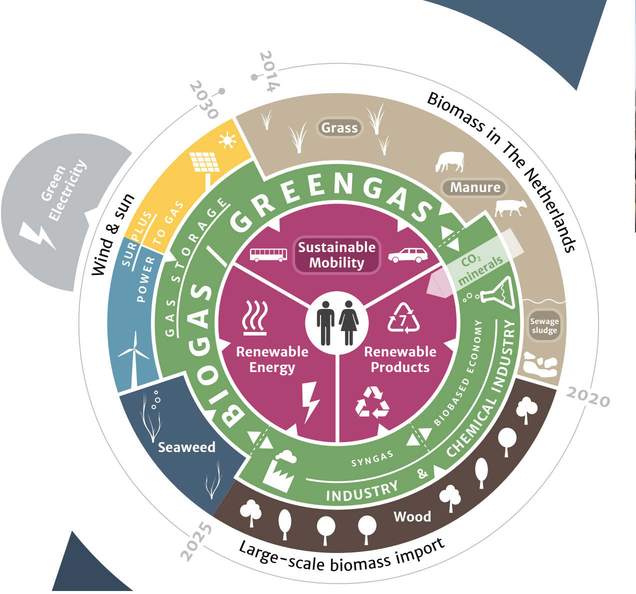
Green Gas Technologies

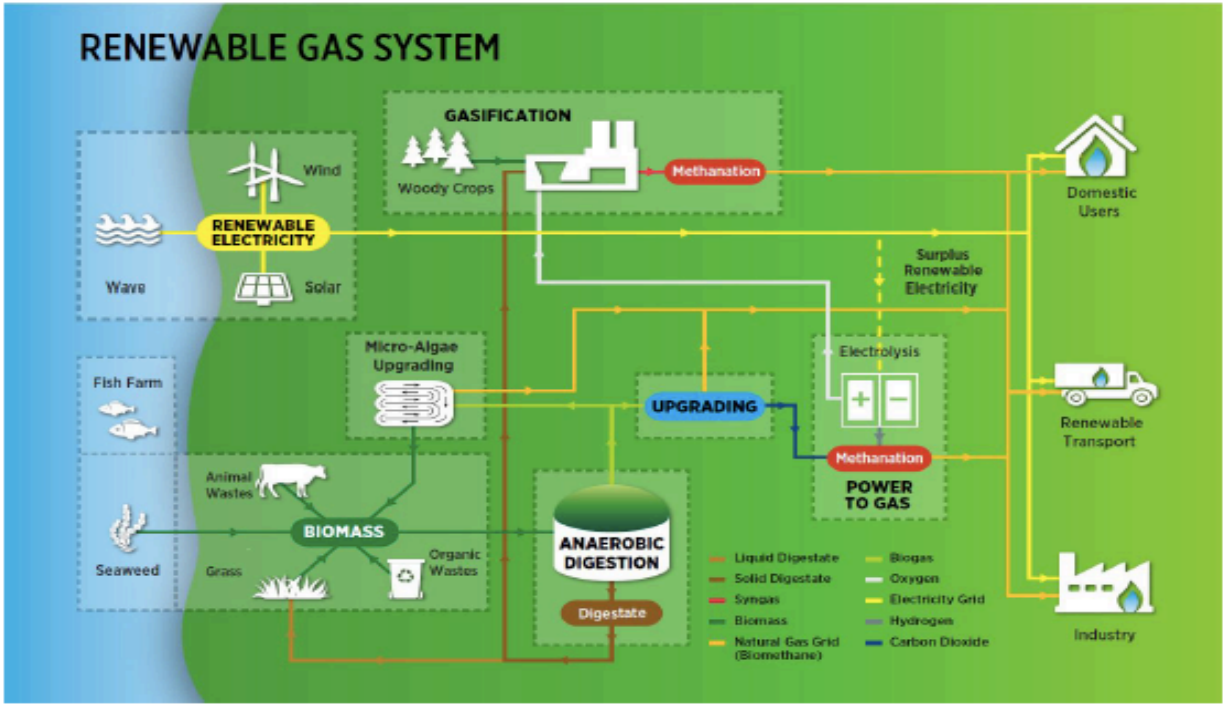
Green gas

Facilitating a future green gas grid though the production of renewable gas

IEA Bioenergy

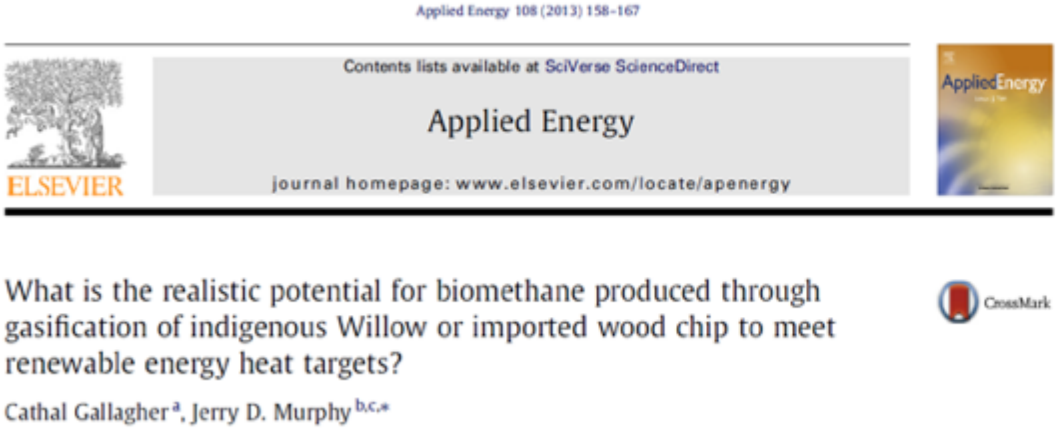
IEA Bioenergy: Task 37: 2018: 2





6 European gas grids have committed to 100% green gas in the gas grid by 2050

Gasification



Applied Energy 108 (2013) 158–167

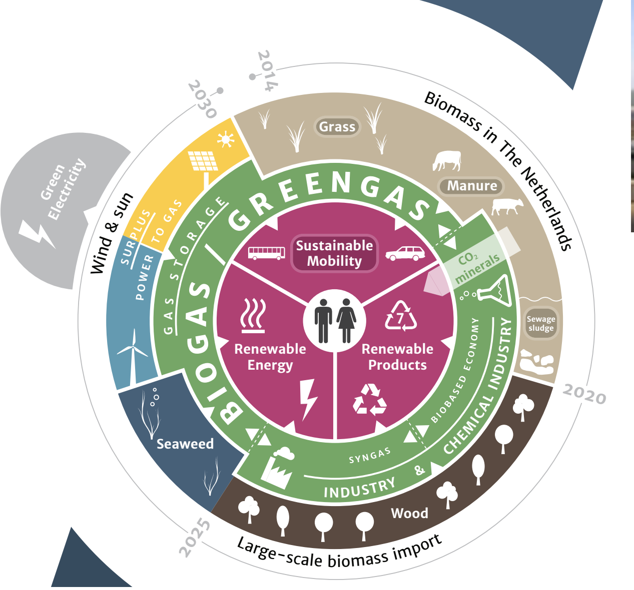
Contents lists available at SciVerse ScienceDirect

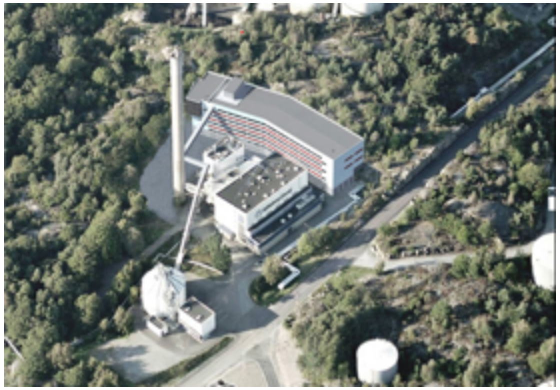
Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

What is the realistic potential for biomethane produced through gasification of indigenous Willow or imported wood chip to meet renewable energy heat targets?

Cathal Gallagher[a], Jerry D. Murphy[b,c,*]





Plant Size MW	50
Land area (ha)	6800
Number of plants required	11
As a % Energy in Transport	5.5%
As a % of agricultural land	1.7%

Seaweed biomethane

Contents lists available at ScienceDirect

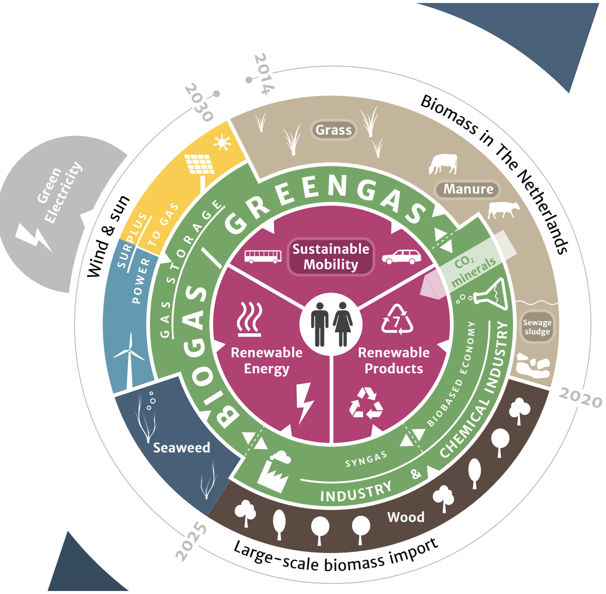
Bioresource Technology

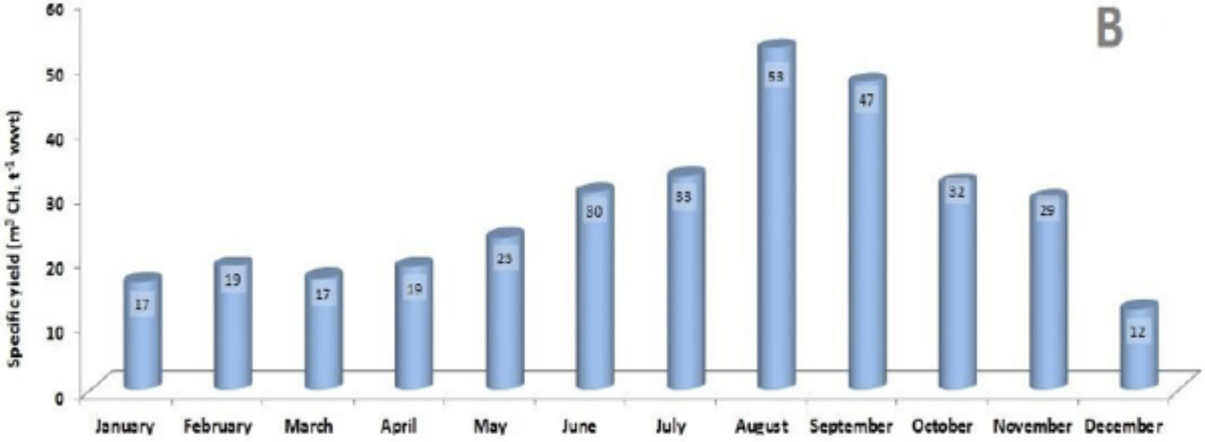
journal homepage: www.elsevier.com/locate/biortech

The effect of seasonal variation on biomethane production from seaweed and on application as a gaseous transport biofuel

Muhammad Rizwan Tabassum[a], Ao Xia[b,*], Jerry D. Murphy[a,c]

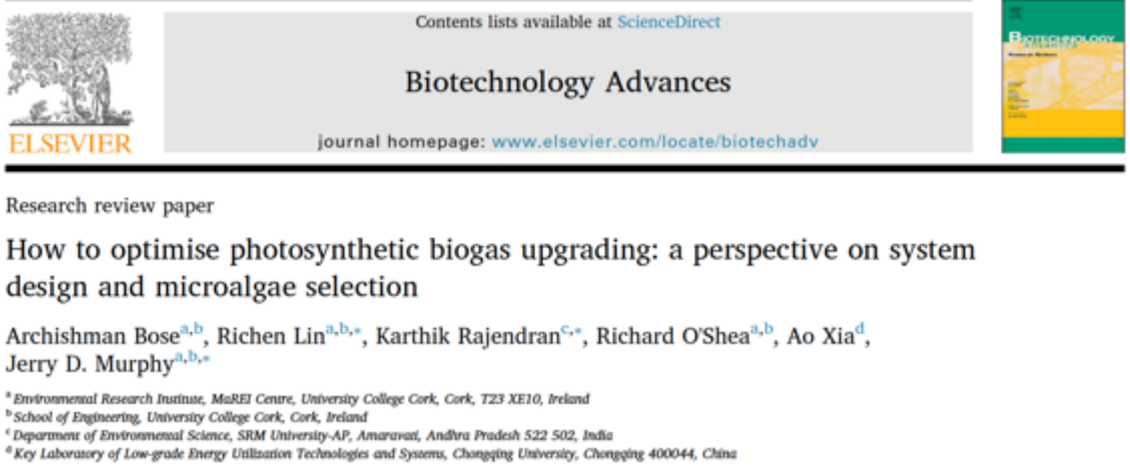
[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China
[c] School of Engineering, University College Cork, Cork, Ireland





Seasonal Variation in biomethane yield from Laminaria Digitata

Carbon capture in micro-algae upgrading



Contents lists available at ScienceDirect

Biotechnology Advances

journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

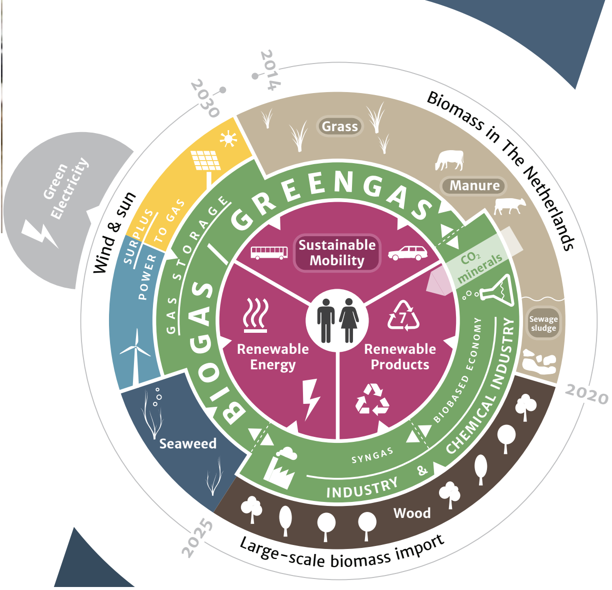
How to optimise photosynthetic biogas upgrading: a perspective on system design and microalgae selection

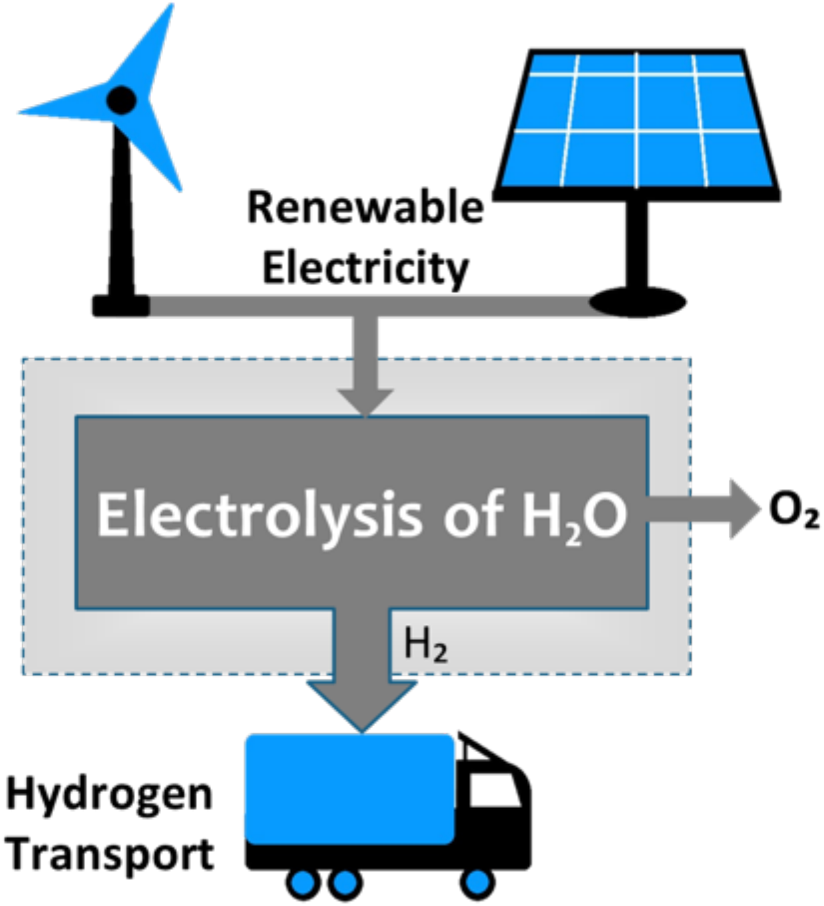
Archishman Bose[a,b], Richen Lin[a,b,*], Karthik Rajendran[c,*], Richard O'Shea[a,b], Ao Xia[d], Jerry D. Murphy[a,b,*]

[a] Environmental Research Institute, MaREI Centre, University College Cork, Cork, T23 XE10, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
[c] Department of Environmental Science, SRM University-AP, Amaravati, Andhra Pradesh 522 502, India
[d] Key Laboratory of Low-grade Energy Utilization Technologies and Systems, Chongqing University, Chongqing 400044, China

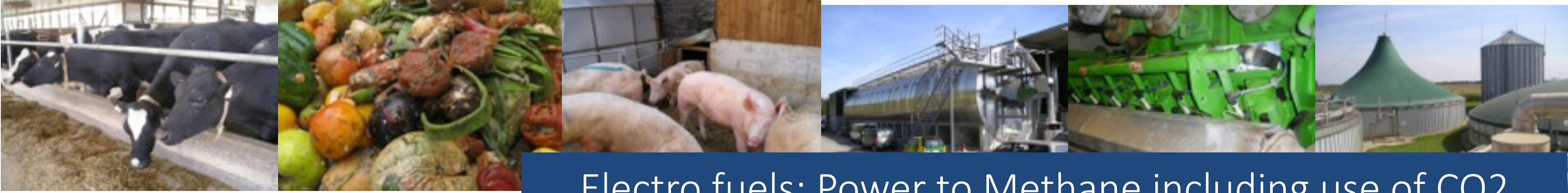
Fig. 3. Biogas Upgrading by microalgae in an alkaline (Carbonate) algal solution via Carbonate/Bicarbonate cycle (The number of markings of each chemical species are indicative only to their relative quantity and not in absolute terms)

Electro fuels: Power to Hydrogen





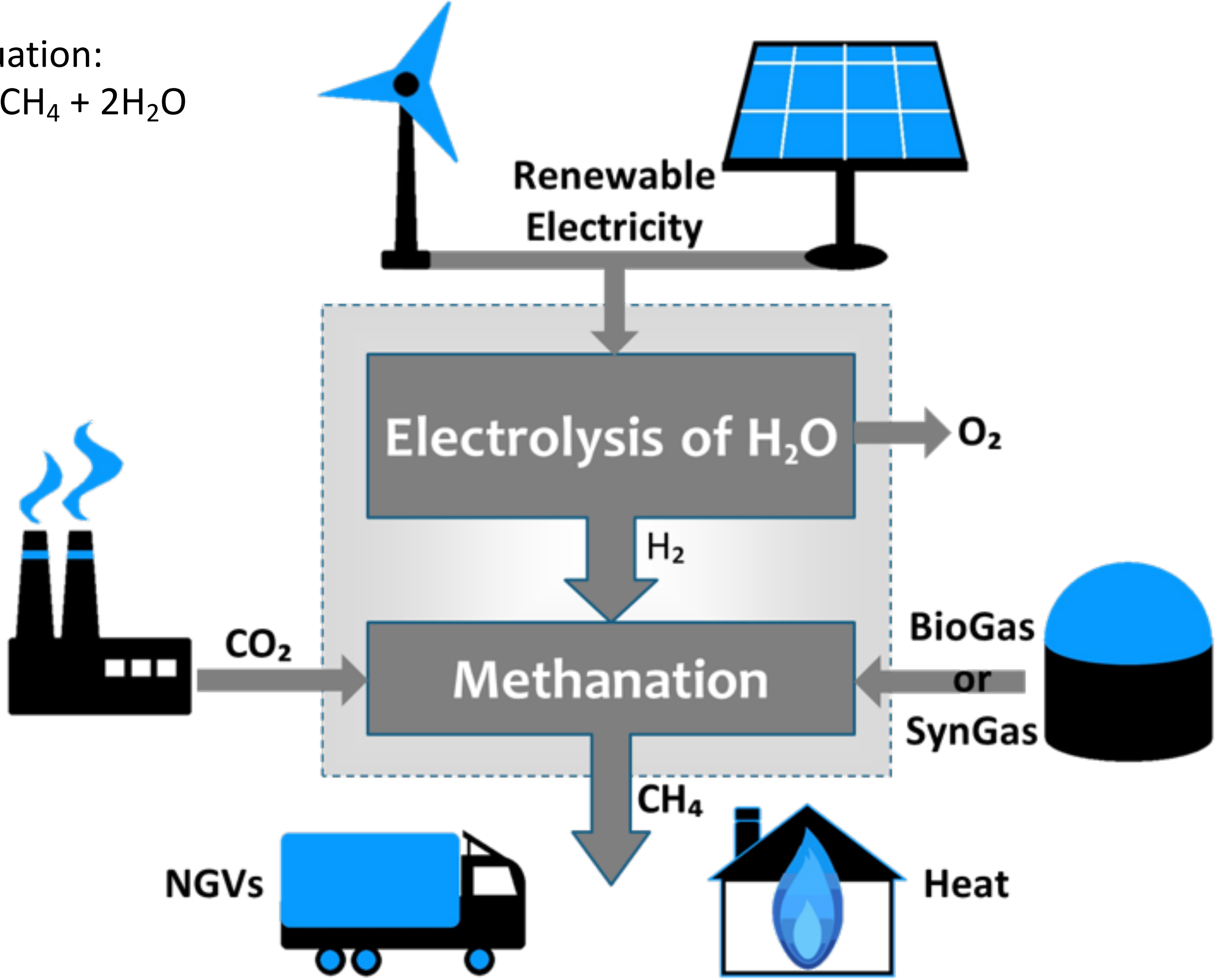
Walney wind farm extension, built in 2017, has a 659MW capacity and cost €1.4 billion.



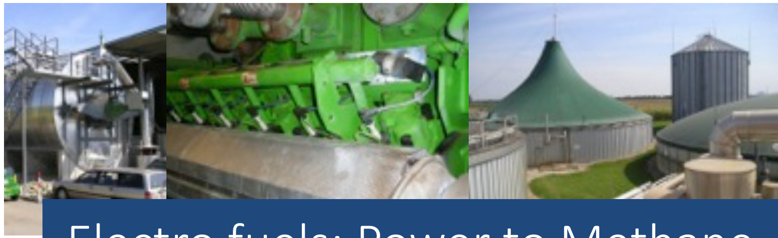
Electro fuels: Power to Methane including use of CO2

Sabatier Equation:

$4H_2 + CO_2 = CH_4 + 2H_2O$



Electro fuels: Power to Methane



Applied Energy 235 (2019) 1061–1071

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Biological methanation: Strategies for in-situ and ex-situ upgrading in anaerobic digestion

M.A. Voelklein*, Davis Rusmanis, J.D. Murphy

MaREI Centre, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
School of Engineering, UCC, Ireland

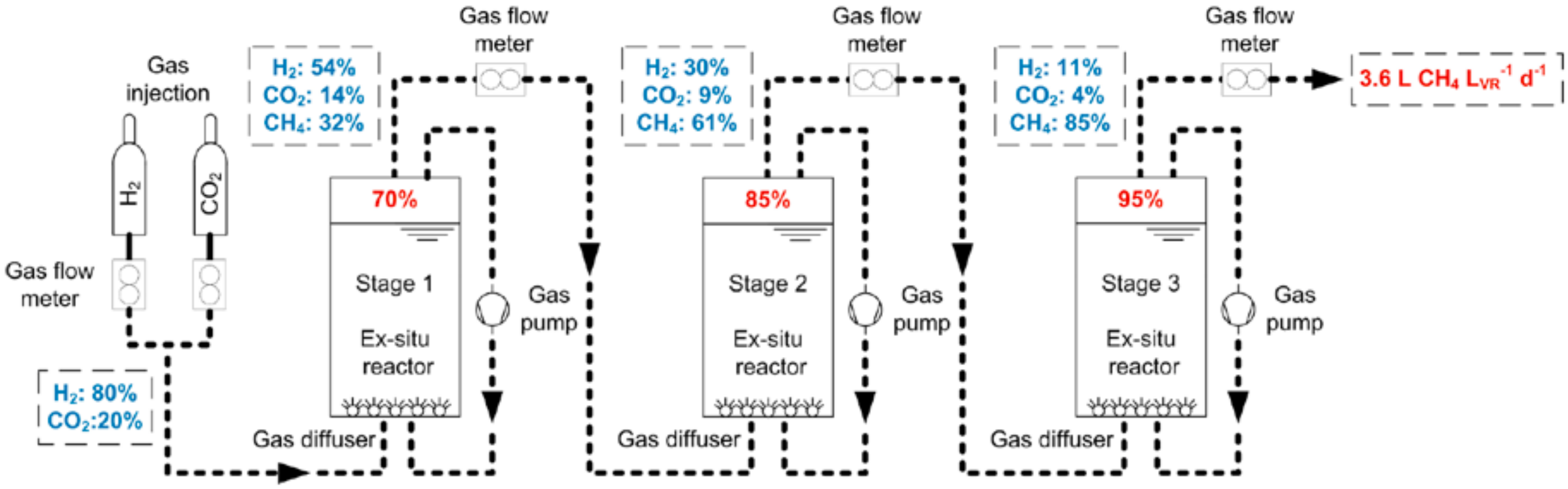
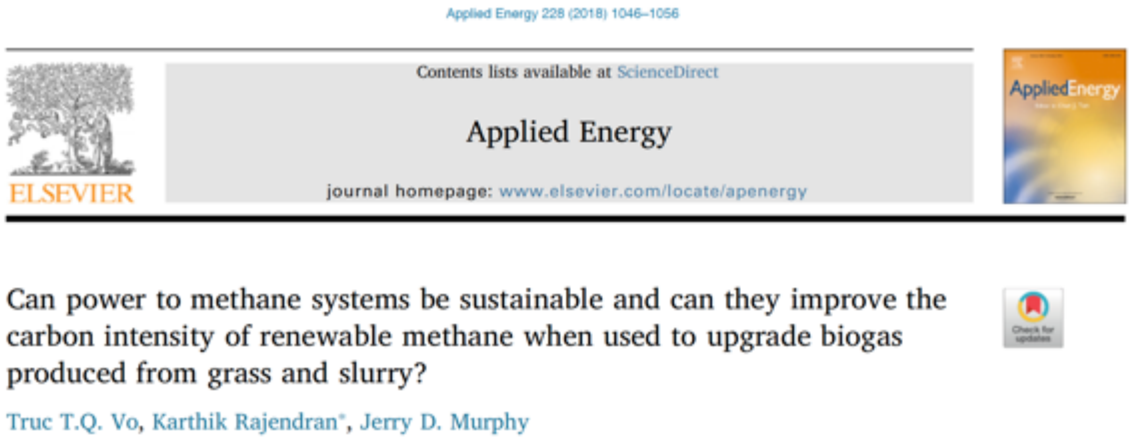


Fig. 6. Theoretic model and approach for a full-scale three-stage sequential ex-situ methanation unit at a methane formation rate of 3.6 L CH_4 L_{VR}^{-1} d^{-1}. The conversion of carbon dioxide to methane corresponds to 70% (after stage 1), 85% (after stage 2) and 95% (after stage 3).

Sustainability of Power to Methane systems



Applied Energy 228 (2018) 1046–1056

Contents lists available at ScienceDirect

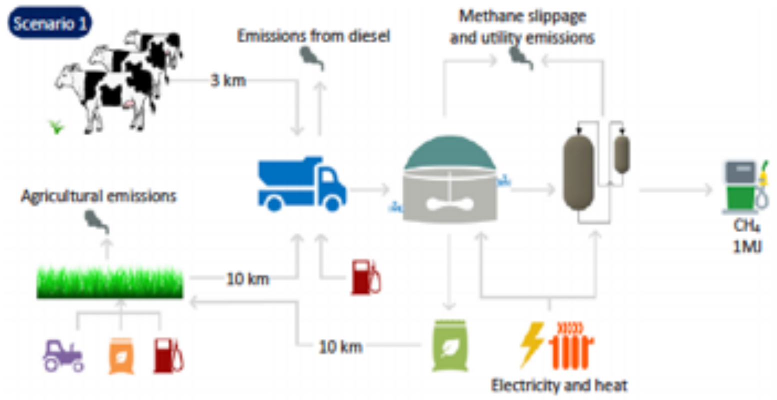
Applied Energy

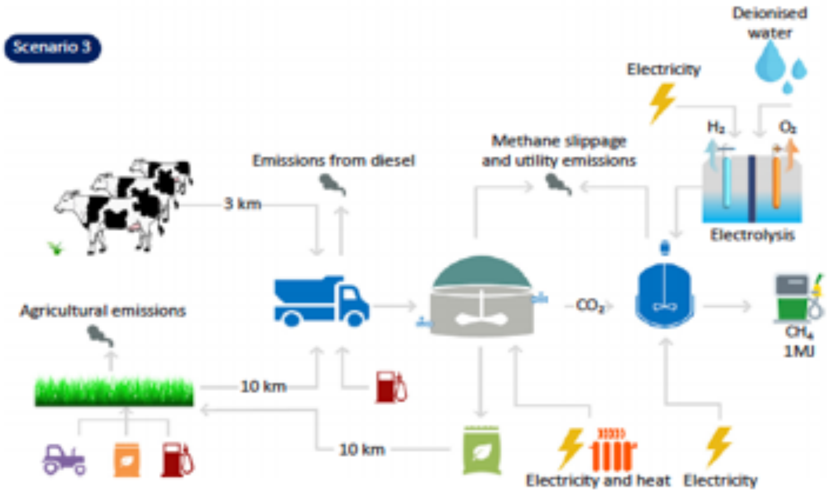
journal homepage: www.elsevier.com/locate/apenergy

ELSEVIER

Can power to methane systems be sustainable and can they improve the carbon intensity of renewable methane when used to upgrade biogas produced from grass and slurry?

Truc T.Q. Vo, Karthik Rajendran*, Jerry D. Murphy





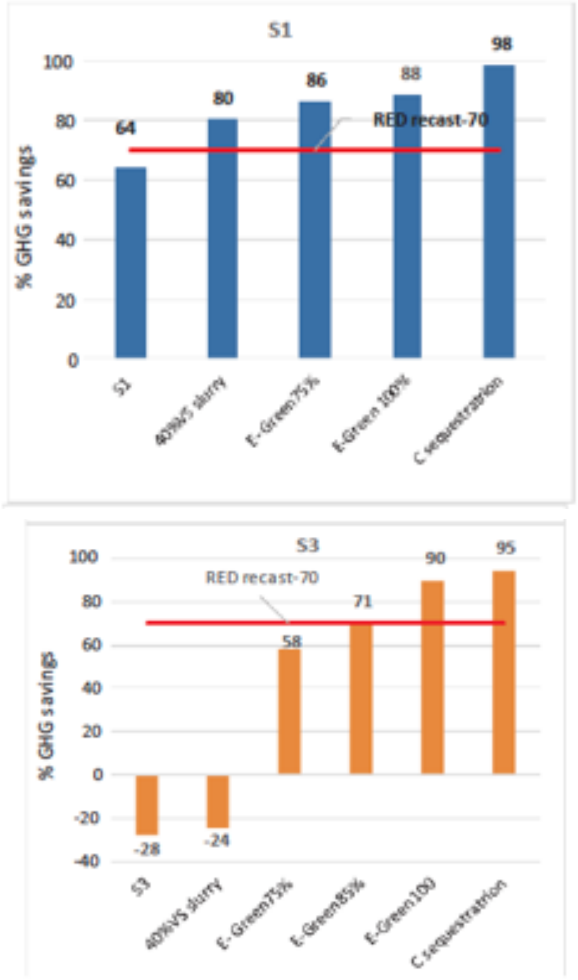
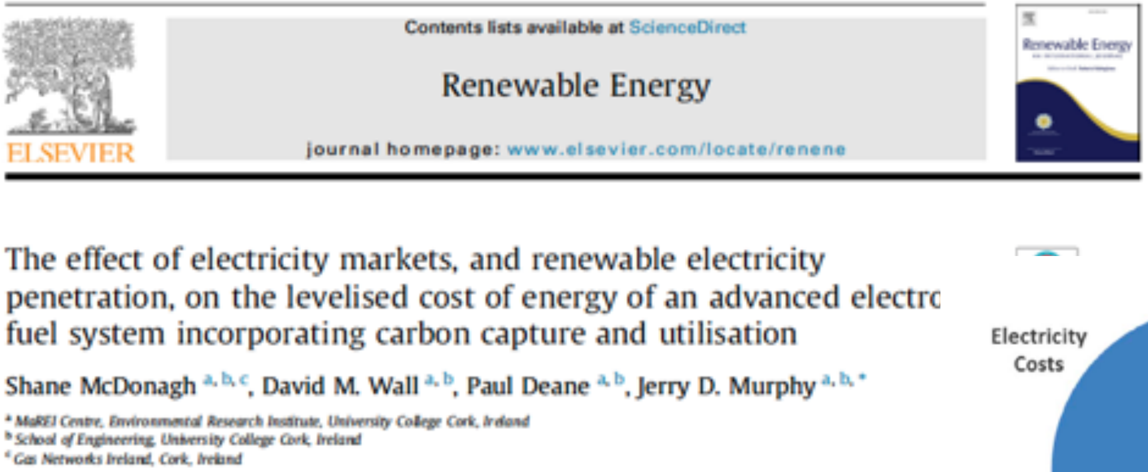


Fig. 6. Cumulative (left to right) percentage GHG savings (e. g C sequestration for S1 included electricity 100% green and 60:40 grass slurry).

Electro fuels - cost



Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

The effect of electricity markets, and renewable electricity penetration, on the levelised cost of energy of an advanced electr fuel system incorporating carbon capture and utilisation

Shane McDonagh [a, b, c], David M. Wall [a, b], Paul Deane [a, b], Jerry D. Murphy [a, b, *]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Ireland
[b] School of Engineering, University College Cork, Ireland
[c] Gas Networks Ireland, Cork, Ireland

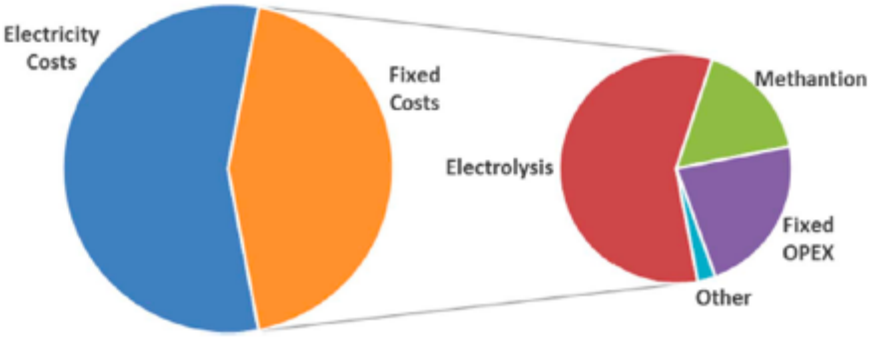
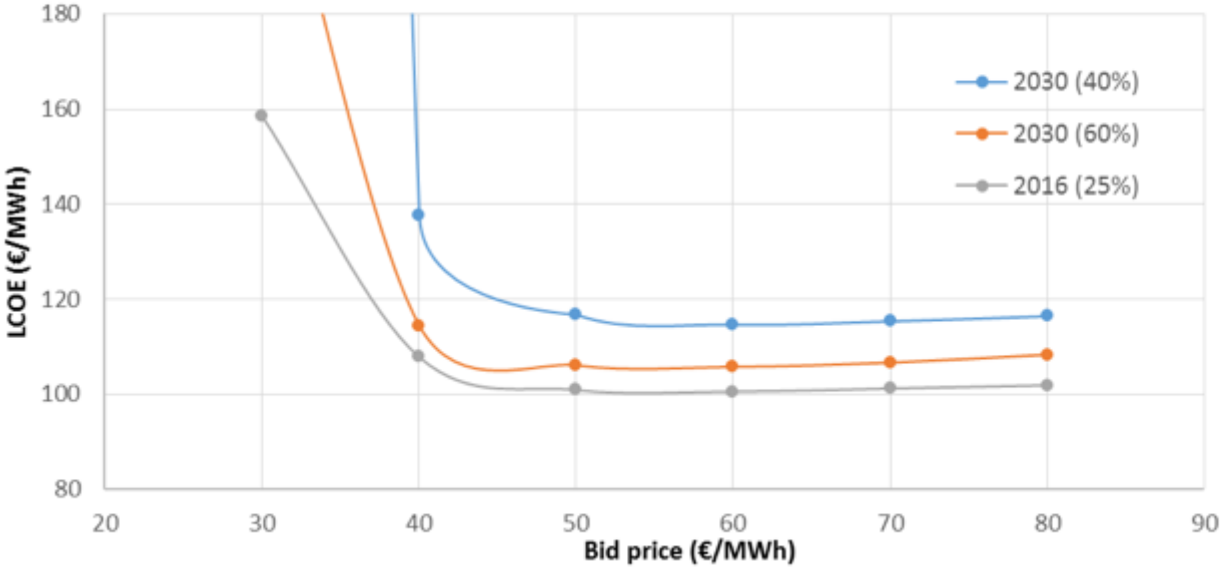
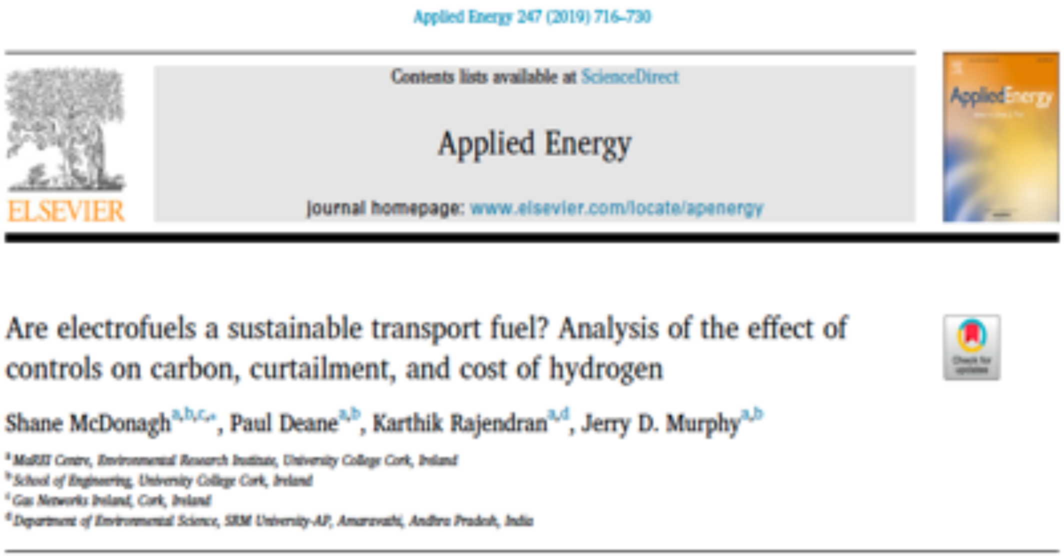


Fig. 3. Breakdown of the system LCOE into its components for 2020 base scenario.



- Low-cost/curtailed energy alone not economically viable…
- Bidding more reduces LCOE…
- Market interaction, not economies of scale…
- Minimised when bidding above marginal cost of generation…

Electro fuels - sustainability



Applied Energy 247 (2019) 716–730

Contents lists available at ScienceDirect

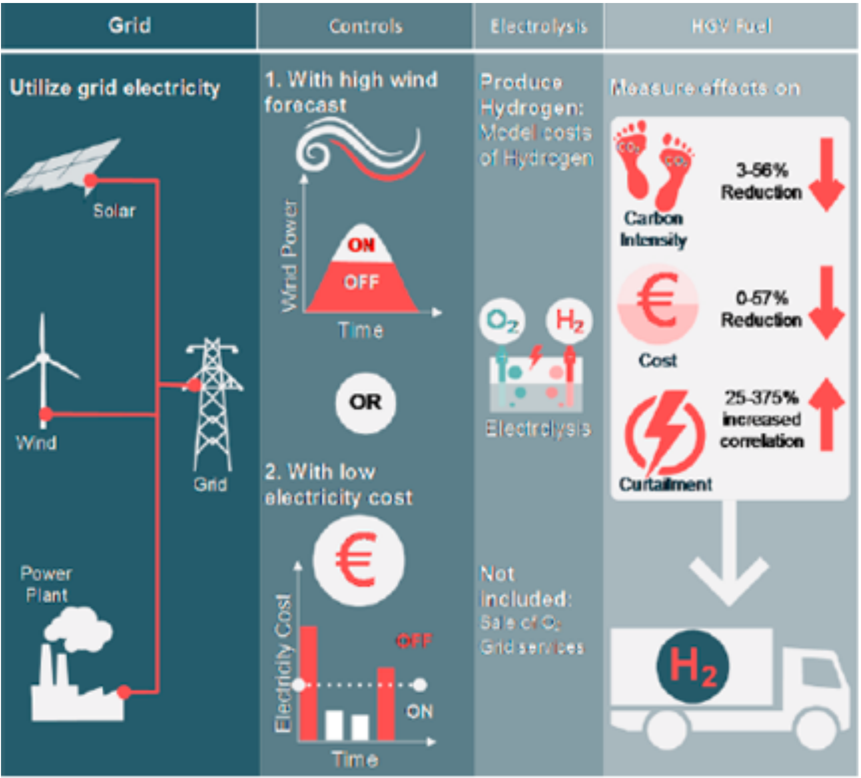
Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Are electrofuels a sustainable transport fuel? Analysis of the effect of controls on carbon, curtailment, and cost of hydrogen

Shane McDonagh[a,b,c,*], Paul Deane[a,b], Karthik Rajendran[a,d], Jerry D. Murphy[a,b]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Ireland
[b] School of Engineering, University College Cork, Ireland
[c] Gas Networks Ireland, Cork, Ireland
[d] Department of Environmental Science, SRM University-AP, Amaravati, Andhra Pradesh, India



Economically optimised PtG system using bid price control

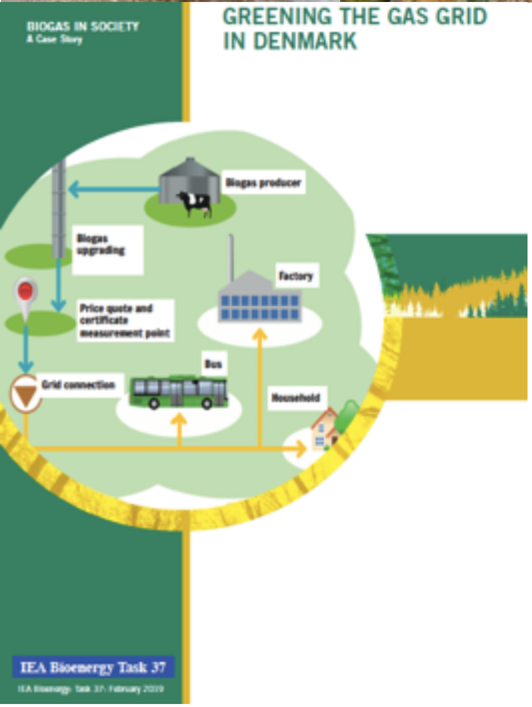
5 to 25% decrease in carbon intensity of energy consumed.

Does not exacerbate the mismatch of supply and demand.

Uses otherwise curtailed electricity 50 to 100% more than average.

Passive control that doesn't require shifts in policy.

Extent of Green Gas in Denmark



BIOGAS IN SOCIETY
A Case Story

GREENING THE GAS GRID
IN DENMARK

IEA Bioenergy Task 37

IEA Bioenergy: Task 37: February 2019

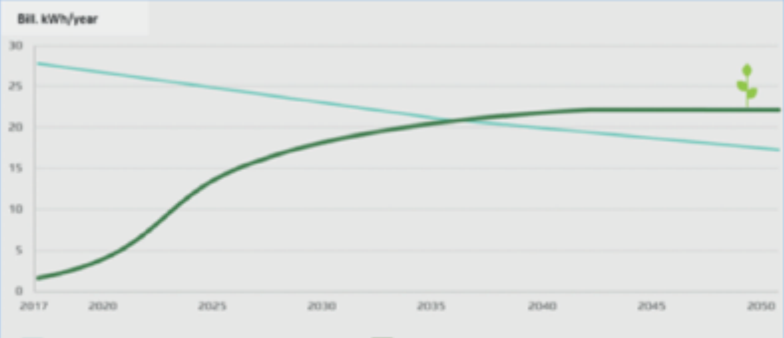


Figure 1: Gas consumption and potential of green gas in Denmark (from Green Gas Denmark)

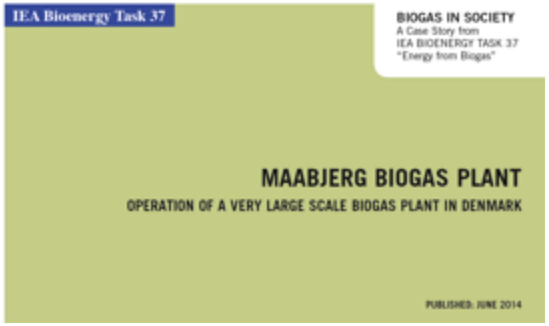
Figure 2: Grid connections for green gas in Denmark (yellow marks indicate connections established in 2017)

Figure 3: Holsted Biogas Plant, producing 20.7 million m³ gas / year. Source: Nature Energy

Denmark which at present has c. 10% renewable gas (with an equal amount going to CHP) intends decarbonising the gas grid with 72PJ of renewable gas by 2035. Addition of Power to Gas systems could see a resource of 100 PJ which would be in advance of gas demand.

Pipelines to extend catchment of biogas

Figure 1: General view of Maabjerg BioEnergy Plant, (Photo: Maabjerg BioEnergy)



IEA Bioenergy Task 37

BIOGAS IN SOCIETY
A Case Story from
IEA BIOENERGY TASK 37
"Energy from Biogas"

MAABJERG BIOGAS PLANT
OPERATION OF A VERY LARGE SCALE BIOGAS PLANT IN DENMARK

PUBLISHED: JUNE 2014

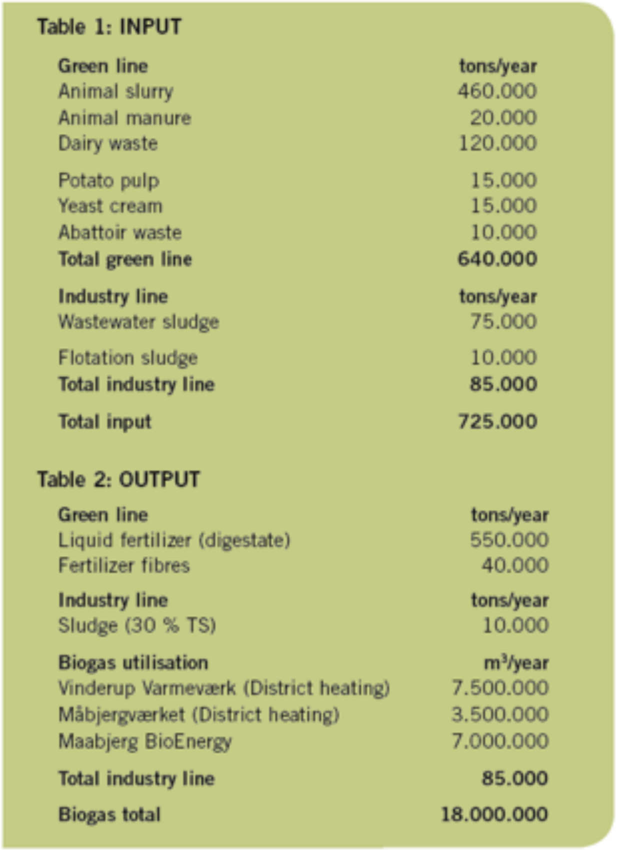


Table 1: INPUT

Green line	**tons/year**
Animal slurry	460.000
Animal manure	20.000
Dairy waste	120.000
Potato pulp	15.000
Yeast cream	15.000
Abattoir waste	10.000
Total green line	**640.000**
Industry line	**tons/year**
Wastewater sludge	75.000
Flotation sludge	10.000
Total industry line	**85.000**
Total input	**725.000**

Table 2: OUTPUT

Green line	**tons/year**
Liquid fertilizer (digestate)	550.000
Fertilizer fibres	40.000
Industry line	**tons/year**
Sludge (30 % TS)	10.000
Biogas utilisation	**m³/year**
Vinderup Varmeværk (District heating)	7.500.000
Måbjergværket (District heating)	3.500.000
Maabjerg BioEnergy	7.000.000
Total industry line	**85.000**
Biogas total	**18.000.000**

Source: Maabjerg BioEnergy

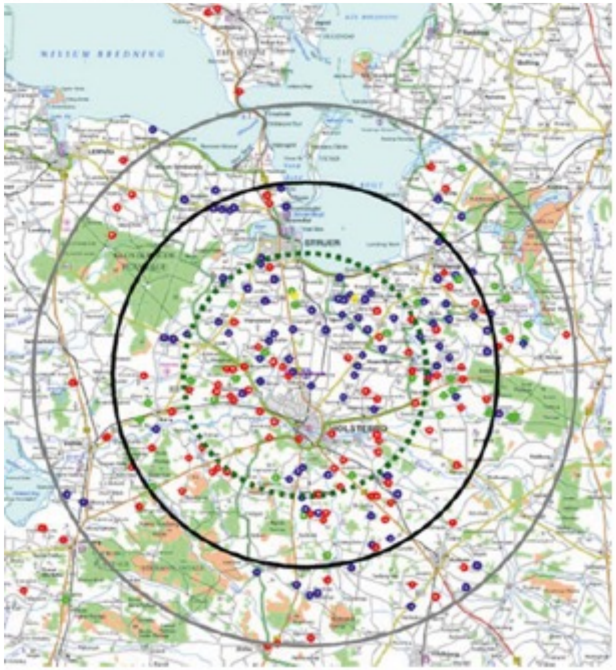


Figure 2: The area of animal slurry collection around the biogas plant, with the average radius of 20 km. Source: Maabjerg BioEnergy

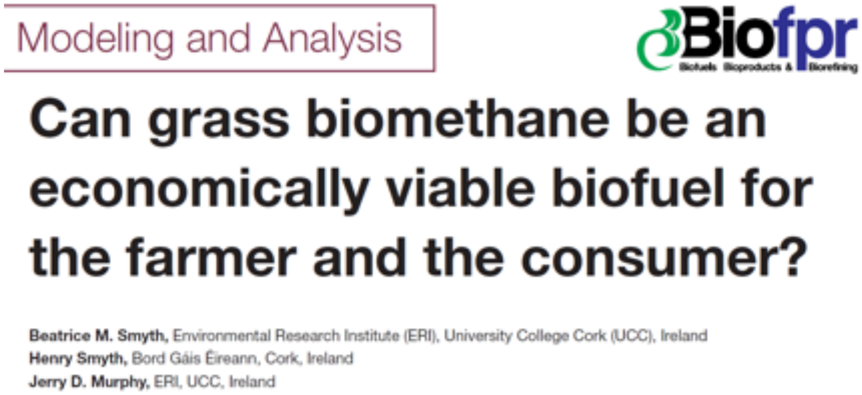
Denmark set a target for 50% slurry digestion by 2020 and has already met this

Pipeline systems consist of double pipes; slurry from collection tanks to digester and sanitized biodigestate from digester back to collection point. Piping system reduces the need for 50 – 70 deliveries per day and facilitates collection of diffuse sources of slurry






Cost of Biogas Systems



Modeling and Analysis

Biofpr
Biofuels Bioproducts & Biorefining

Can grass biomethane be an economically viable biofuel for the farmer and the consumer?

Beatrice M. Smyth, Environmental Research Institute (ERI), University College Cork (UCC), Ireland
Henry Smyth, Bord Gáis Éireann, Cork, Ireland
Jerry D. Murphy, ERI, UCC, Ireland

1 m^3 CH$_4$ = 10 kWh= 1L diesel equivalent

As a rule of thumb:

- 22c/m3 biomethane to make biogas,
- 22c/m3 to upgrade to biomethane,
- 11c/m3 biomethane to compress and 11c/m3 biomethane to distribute.
- <u>This is 66c/m3 biomethane or 66c/L diesel equivalent or 6.6c/kWh.</u>

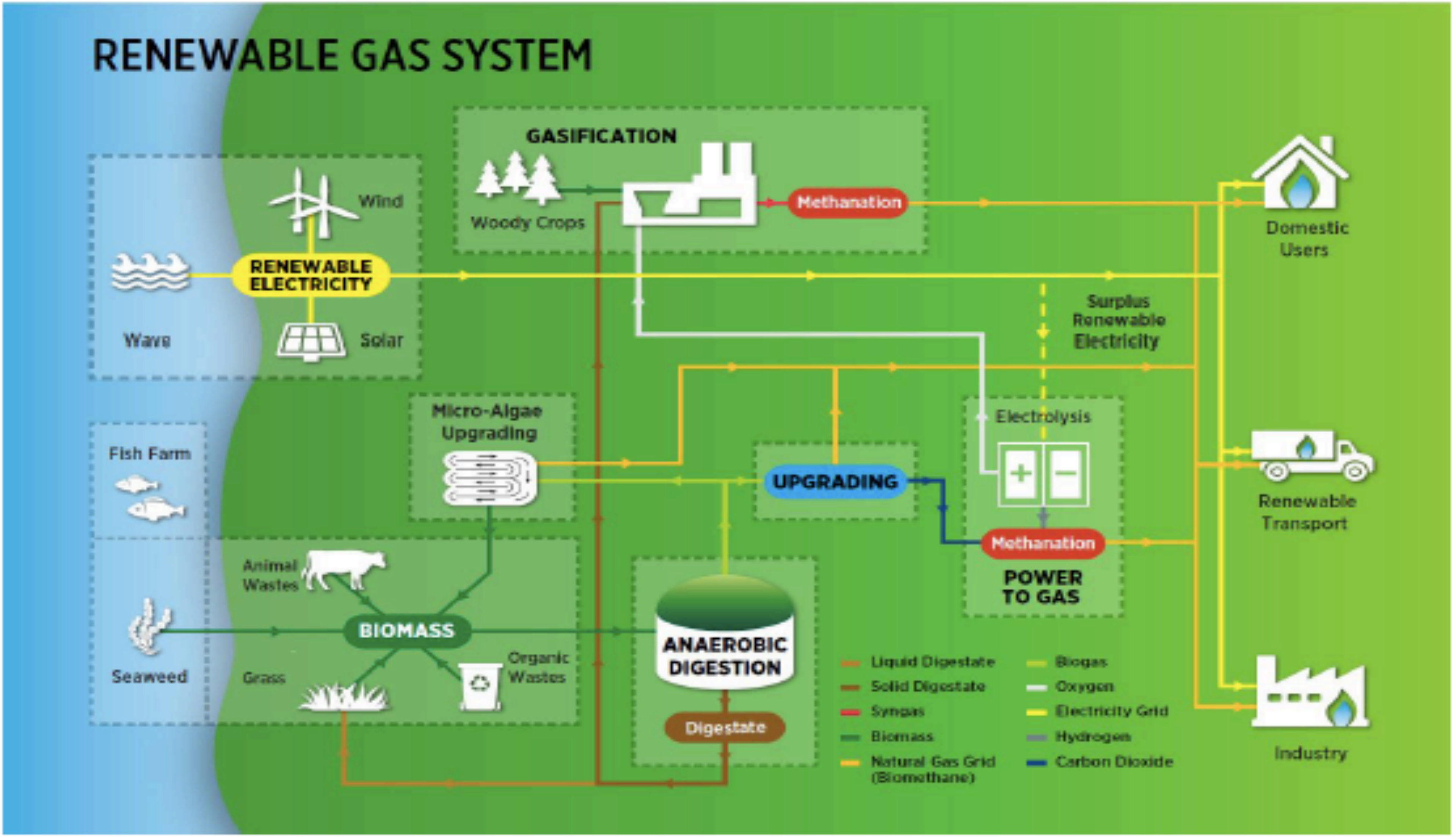
If you <u>buy all the feedstock</u> this rises. Say €35/ t silage adds 33c/ m3. Overall cost <u>of 99 c/m3</u> or 9.9 c/kWh.

For <u>food waste</u> there is a decrease in cost; fee of €35/t drops the cost by 33c/m3 to <u>33c/m3</u> or 3.3 c/kWh

Highlights

1. **How do we cost the asset value associated with the circular economy benefits of anaerobic digestion?** Biogas systems include for waste treatment and can help decarbonise agriculture. The by-products include for organic biofertilizer & green CO2. Biogas systems improve both ground water and surface water quality. One third of Irish wells are contaminated.
2. **The EU requires 3.5% advanced biofuel by 2030.** Biogas produced from perennial rye grass is a viable commercially available advanced biofuel, which is cheaper than other advanced biofuels such as FT diesel. This is particularly important for **haulage and coaches** as there are few alternatives to decarbonise this sector of transport.
3. **Grass and slurry in a 60:40 VS ratio results in a 80% GHG savings**. This allows compliance with the 65% and 80% GHG savings required by the RED for transport and heat respectively.
4. **The cost of biomethane varies between 33 to 99 c/L diesel equivalent (3.3 to 9.9 c/kWh)**
5. **Policy such as the Danish target of 50% digestion of slurries by 2020 can increase the slurry resource significantly**. 80% of the geographical specific resource of grass and slurry is available within 25 km of the gas grid. With power to gas we can generate 40 PJ/a (in excess of HGV demand)

Green Gas Technologies



IEA Bioenergy Biogas Task

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